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(71) Applicant: APPLIED MATERIALS, INC. [US/US];
3050 Bowers Avenue, Santa Clara, California 95054 (US).

(72) Inventor; and

(71) Applicant (for US only): HERMANN, Uwe [DE/DE];
Seligenstädter Str. 24, 63791 Karlstein am Main (DE).

(74) Agent: ZIMMERMANN & PARTNER PATENTAN-
WÄLTE MBB; Josephspitalstr. 15, 80331 München (DE).

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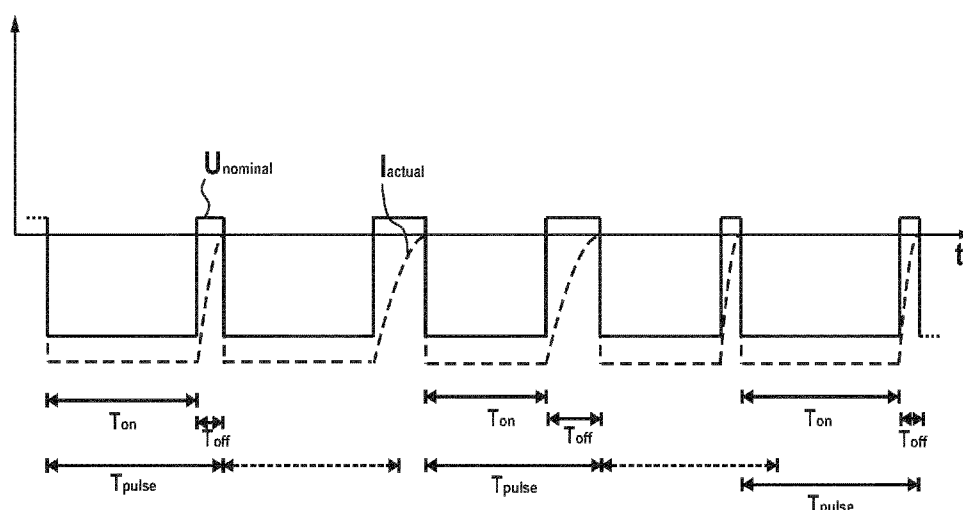
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(54) Title: PULSED DC POWER SUPPLY

Fig. 2



(57) Abstract: A pulsed DC power supply is provided. The pulsed DC power supply is configured for providing unipolar pulsed DC power. The pulsed DC power supply includes a pulsing unit for alternately setting a nominal on-cycle DC voltage during on-cycles and a nominal off-cycle voltage during off-cycles of unipolar pulse cycles of the pulsed DC power supply. The pulsed DC power supply includes a current measurement unit configured to measure an off-cycle current during an off-cycle, and a zero-line determination unit configured to determine a presence of a zero-line condition of the measured off-cycle current. The pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the zero-line condition of the measured off-cycle current.

PULSED DC POWER SUPPLY

TECHNICAL FIELD

[0001] Embodiments relate to a pulsed DC power supply for providing unipolar pulsed DC power, and a method of operation of such a pulsed DC power supply. Further embodiments relate to a deposition system, e.g., a sputter deposition system, including such a pulsed DC power supply.

BACKGROUND

[0002] Pulsed DC sputtering is a physical vapor deposition process (PVD process) with applications, e.g., in semiconductor and coating industries. The abbreviation “DC” stands for direct current, in contrast to alternating current. Pulsed DC Sputtering is particularly effective for the sputtering of metals and dielectric coatings, and is often used with reactive sputtering in which a chemical reaction occurs in the plasma between the vaporized target material and ionized gases like oxygen to form deposition molecules such as silicon oxides. In conventional DC sputtering, e.g., in reactive sputtering of aluminum, titanium or silicon, the targets can become charged and arcs can form that strongly degrade the quality of the deposited film or layer.

[0003] Pulsing the DC voltage that is applied to the targets reduces arcing. Arcing can result from a charge building up on dielectric layers formed in the course of a deposition process. Arcing may thus not be very problematic in the beginning of a deposition process, but can increase dramatically later on, leading to process failure of the coating application. Arcs can create deteriorate the quality of a deposited layer or film and can make power application to the sputter targets unstable.

[0004] In unipolar pulsed DC sputtering, sputtering takes place while the pulsed DC voltage is on during an on-cycle (duty cycle), i.e., while it assumes a typically negative value of a few hundred volts. During a subsequent off-cycle of the pulsed DC voltage the targets, and depending on the process possibly also the substrate, are discharged. During the off-cycle the value of the voltage can be zero or a positive value of a few tens of volts, often called a reverse pulse. The process conditions may change over the process time, e.g., the way that charge builds up on the targets, and pulsing the DC voltage is typically not enough to fully prevent arcing. Therefore, pulsed DC voltage supplies can include arc suppression circuitry which detects the

formation of an arc through changes in the target voltage, and immediately initiates one or more extraordinary off-periods, typically one or more reverse pulses, to quench the arc. The normal pulsed DC cycles resumes once the arc is quenched.

[0005] The pulse frequency and the lengths of the on-cycle and of the off-cycle are set in the pulsed DC voltage supplies by an operator. The setting of these process parameters is based on operator experience. If operator experience is insufficient to properly set these process parameters, or if the sputter process behaves in an unexpected way or simply changes over time, there may be many arc formations that need to be suppressed by the arc suppression circuitry, or the on-time during which sputtering occurs may be too short, and the deposition rate of the sputter deposition process will be negatively influenced.

[0006] Therefore, there is a need for improved pulsed DC voltage supplied, methods of operating the same, and deposition systems employing such pulsed DC voltage supplies.

SUMMARY

[0007] In light of the above, a device and a method according to the independent claims are provided. Further details can be found in the dependent claims, the description, and the drawings.

[0008] According to one embodiment, a pulsed DC power supply is provided. The pulsed DC power supply may be configured for providing unipolar pulsed DC power. The pulsed DC power supply includes a pulsing unit for alternately setting a nominal on-cycle DC voltage during on-cycles and a nominal off-cycle voltage during off-cycles of unipolar pulse cycles of the pulsed DC power supply. The pulsed DC power supply includes a current measurement unit configured to measure an off-cycle current during an off-cycle, and a zero-line determination unit configured to determine a presence of a zero-line condition of the measured off-cycle current. The pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the zero-line condition of the measured off-cycle current.

[0009] According to another embodiment, a pulsed DC power is provided. The pulsed DC power supply may be configured for providing unipolar pulsed DC power. The pulsed DC power supply includes a pulsing unit configured to set a nominal on-cycle DC voltage during an on-cycle of a unipolar pulse cycle of the pulsed DC power supply and configured to set a nominal off-cycle voltage during an off-cycle of a unipolar pulse cycle of the pulsed DC power

supply. The pulsed DC power supply includes a measurement unit configured to measure at least one electrical quantity of the pulsed DC power supply. The pulsed DC power supply includes an evaluation unit configured to determine the presence of a predetermined condition from an evaluation of measurement values of the measured at least one electrical quantity. The pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the predetermined condition.

[0010] Further, a sputter deposition system is provided. The sputter deposition system includes a sputter target and a pulsed DC power supply according to embodiments described herein. The pulsed DC power supply is connected to the sputter target.

[0011] According to another embodiment, a method of operation of a pulsed DC power supply is provided. The pulsed DC powers supply may some or all features according to embodiments described herein. The pulsed DC powers supply provides unipolar pulsed DC power. The method includes setting a nominal on-cycle DC voltage for a first pulse cycle of the pulsed DC power supply, and outputting an on-cycle DC voltage and an on-cycle DC current by the pulsed DC power supply. The method includes setting a nominal off-cycle DC voltage to trigger an off-cycle of the first pulse cycle, and measuring an off-cycle current of the off-cycle of the first pulse cycle by the pulsed DC power supply. The method includes determining a presence of a zero-line condition of the off-cycle current from the measurement of the off-cycle current. The method includes setting a nominal on-cycle DC voltage for a second pulse cycle when the zero-line condition of the off-cycle current of the first pulse cycle is determined to be present.

[0012] The disclosure is also directed to apparatuses for carrying out the disclosed methods, including apparatus parts for performing each of the described features of the methods. These method features may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Further aspects are also directed to methods according to which the described pulsed DC power supplies or sputter deposition systems operate or are manufactured or are used. The methods may include method parts for carrying out every function of the pulsed DC power supplies or sputter deposition systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] So that the manner in which the above recited features can be understood in detail, a more particular description may be had by reference to embodiments. The accompanying drawings relate to embodiments and are described in the following:

- Fig. 1 illustrates the characteristics of a unipolar pulsed DC voltage;
- Figs. 2-3 illustrate methods of operating a pulsed DC power supply according to embodiments described herein;
- Fig. 4 shows a pulsed DC power supply according to embodiments described herein;
- Fig. 5 shows a sputter deposition system according to embodiments described herein;
- Fig. 6 shows a method of operating a pulsed DC power supply according to embodiments described herein.

DETAILED DESCRIPTION OF EMBODIMENTS

[0014] Reference will now be made in detail to the various exemplary embodiments, one or more examples of which are illustrated in each figure. Each example is provided by way of explanation and is not meant as a limitation. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet further embodiments. It is intended that the present disclosure includes such modifications and variations.

[0015] Within the following description of the drawings, the same reference numbers refer to the same or similar components. Generally, only the differences with respect to the individual embodiments are described. The structures shown in the drawings are not necessarily depicted true to scale or angle, and may exaggerate features for a better understanding of the corresponding embodiments.

[0016] Fig. 1 shows the characteristics of a unipolar pulsed DC voltage, which may be applied by a pulsed DC power supply to a sputter target in a sputter deposition process. Time t is shown

on the abscissa and voltage U is shown on the ordinate. Arbitrary units are used. The voltage takes a negative, constant value during on-cycles (duty cycles) in Fig. 1. The on-period of an on-cycle, i.e., the length of time that the on-cycle lasts, is designated as T_{on} . The voltage takes a small, positive, constant value during off-cycles (reverse pulses) in Fig. 1. The off-period of the off-cycle, i.e., the length of time that the off-cycle lasts, is designated as T_{off} . One pulse consists of an on-cycle and an off-cycle, or in other words of an on-pulse and a reverse pulse. A pulse is also called a pulse cycle herein due to the repeating pattern of pulses. The pulse period or pulse length, i.e., the length of time that a pulse lasts, is designated as T_{pulse} and is the sum of T_{on} and T_{off} . The operating frequency or pulse frequency, designated as F_{pulse} , is the inverse of the pulse period.

[0017] The pulse frequency, the length of the on-cycle (duty cycle period) and the length of the off-cycle (reverse pulse period) may be set by an operator based on operator experience. For instance, the operator may set a nominal pulse frequency, and a may set either the length of the on-cycle or a ratio between the lengths of the on-cycle and of the off-cycle, and T_{pulse} , T_{on} and T_{off} follow by the mathematical relations explained above. If such a unipolar pulsed DC voltage is output from a pulsed DC voltage supply and applied to a sputter target, sputtering can take place during the on-cycle, while the reverse pulse reduces arcing due to discharging the sputter target. But if operating parameters of the pulsed DC voltage supply like pulse frequency and reverse pulse period are not properly set, or sputter process conditions change over time or behave unexpectedly, arc formation can still become frequent. Frequent arc formation can necessitate a frequent use of extraordinary measures like arc suppression by special arc suppression circuitry, lowering the efficiency and possibly quality of the sputter deposition process.

[0018] In embodiments described herein, a pulsed DC power supply for providing unipolar pulsed DC power determines a condition when to start an on-cycle of a next pulse cycle based on measuring one or more electrical quantities during the current pulse cycle, in particular during the off-cycle of the current pulse cycle. When the pulsed DC power supply provides unipolar pulsed DC power for a sputter deposition process, the condition when to start the on-cycle of the next pulse cycle can be a charge removal condition, i.e., a condition indicating that charge which had built up on the sputter target or on the sputter targets has been removed by the off-cycle voltage of the off-cycle (reverse pulse voltage). The next pulse cycle then starts with an on-cycle only after the charge removal condition is fulfilled. Contrary to the situation

shown in Fig. 1, the length of the off-cycle, i.e., the off-cycle period, may vary in dependence of measurements of actual electrical quantities such as actual current and/or actual voltage. In Fig. 1, the length of the off-cycle could only vary if the operator set nominal operating parameters differently, e.g., nominal operating frequency (and thus the nominal pulse length) or nominal length of either the off-cycle or of the on-cycle.

[0019] The pulsed DC power supply according to embodiments described herein therefore does not simply set nominal on-cycle voltage and nominal off-cycle voltage at times predetermined by operating parameters set by an operator, but can intelligently react to actually occurring process situations as perceived by the pulsed DC power supply. Since the off-cycle of the current pulse cycle is maintained until a specific condition of actual electric quantities is fulfilled, in particular a charge removal condition indicating removal of the charge from the sputter target(s), the pulsed DC power supply can always guarantee full or at least sufficient charge removal to reduce or even prevent arcing even if the process conditions of the sputter deposition process change.

[0020] The charge removal condition may be a zero-line condition of the actual off-cycle current as measured by the pulsed DC power supply. That means, the on-cycle DC voltage is set again to start the on-cycle of the next pulse cycle once the pulsed DC power supply determines that the measured off-cycle current is zero or sufficiently close to zero. Without wishing to be bound by any particular theory, it is believed that the presence, i.e. the fulfillment, of such a zero-line condition of the actual off-cycle current indicates sufficient charge removal from the sputter target(s).

[0021] Since the off-cycle period is variable from pulse cycle to pulse cycle due to a dependence on actual electrical quantities measured by the pulsed DC power supply, the sum of the nominal on-cycle period T_{on} and of the variable off-cycle period T_{off} need not necessarily equal the nominal pulse period T_{pulse} , being the inverse of the nominal pulse frequency F_{pulse} . According to some embodiments, the on-cycle period is adapted (first mechanism). The on-cycle period may be adapted so that the sums of the on-cycle periods and of the off-cycle periods converge to the nominal pulse period, or are at least on average equal to or close to the nominal pulse period. According other embodiments, the pulse frequency and thus the pulse period is adapted instead (second mechanism). Both mechanisms can also be implemented jointly, coordinated by specific conditions when to apply the first mechanism and when to apply the second mechanism. The first mechanism (adaptation of the on-cycle period) may be the default

mechanism and used for fine-tuning the output of the pulsed DC power supply. The second mechanisms (adaptation of the pulse frequency) may be used more sparsely for coarser adjustments, e.g., if some quality conditions cannot be met by fine adjustments with the first mechanism.

[0022] Fig. 2 illustrates a method of operation of a pulsed DC power supply. Time t is shown on the abscissa, and the nominal voltage U_{nominal} set by the pulsed DC power supply and the actual current I_{actual} measured by the pulsed DC power supply are schematically shown in arbitrary units on the ordinate. Five pulse cycles are exemplarily shown in Fig. 2. During the on-cycles of the pulse cycles, the nominal voltage is set to a constant on-cycle voltage whose value is negative, e.g., a few hundred volts. During the off-cycles (reverse pulses) of the pulse cycles, the nominal voltage is set to a constant off-cycle voltage whose value is positive and at least an order of magnitude smaller than the on-cycle voltage, e.g., a few ten volts. The pulsed DC power supply measures the actual current I_{actual} at least during each off-cycle, and triggers the next pulse cycle, beginning with the on-cycle, only once the pulsed DC power supply has determined from the measured actual current I_{actual} that a zero-line condition of the actual current I_{actual} is present. This behavior is visible in Fig. 2 for the five pulse cycles shown, where the nominal voltage U_{nominal} is set to the negative on-cycle voltage once it is determined from the measurement results that the actual current I_{actual} is zero or substantially zero.

[0023] As can be seen, e.g., from the second pulse cycle shown in Fig. 2, the nominal voltage is not necessarily set to the on-cycle voltage once the nominal pulse period is over, as was the case in Fig. 1. The nominal pulse period is shown with an arrow represented by a dashed line for the second pulse cycle because the actual pulse period is longer for this second pulse cycle. The reason is that the actual current I_{actual} fulfills a zero-line condition only after the nominal pulse period has expired. The pulsed DC power supply waits with triggering the on-cycle of the next, third pulse cycle until the zero-line condition is actually determined to be present, irrespective of the nominal pulse period.

[0024] In the embodiment shown in Fig. 2, the pulsed DC power supply determines the length of the off-cycle of the second pulse cycle, i.e., the off-cycle period of the second pulse cycle. For the third pulse cycle, the pulsed DC power supply makes the on-cycle period shorter, e.g., by setting the on-cycle period T_{on} to the difference between the nominal pulse period and the determined off-cycle period of the second pulse cycle. Conversely, as illustrated by the fourth and fifth pulse cycle shown in Fig. 2, the pulsed DC power supply may make the on-cycle

period longer. In the fourth pulse cycle, the zero-line condition of the actual current I_{actual} is reached before the nominal pulse period (shown again with an arrow with dashed lines) has expired. By setting the on-cycle period T_{on} to the difference between the nominal pulse period and the determined off-cycle period of the fourth pulse cycle, the on-cycle period T_{on} becomes longer during the fifth pulse cycle. The nominal pulse period T_{pulse} and thus the nominal pulse frequency $F_{\text{pulse}}=1/T_{\text{pulse}}$ does not change during the pulse cycles shown in Fig. 2. Only the on-cycle period is adapted to the variable off-cycle period (first mechanism).

[0025] When the pulsed DC power supply is used for providing unipolar pulsed DC power for a sputter deposition process, sputtering takes place only during the on-cycle (duty cycle). Therefore, the pulsed DC power supply outputting unipolar pulsed DC power as shown in Fig. 2 can reduce arcing due to ensuring that a charge removal condition in the form of a zero-line condition is met and can enhance efficiency of a sputter deposition process due to maximizing the on-cycle period under the constraint of a given nominal pulse period. The duty factor is maximized without need for operator intervention. The duty factor shall be understood as the ratio between the on-cycle period and the nominal pulse period.

[0026] Fig. 3 illustrates a further method of operation of a pulsed DC power supply. Three pulse cycles are shown, of which the first two pulse cycles are the same as in Fig. 2. Further description thereof is omitted. As in Fig. 2, the pulsed DC power supply determines the length of the off-cycle of the second pulse cycle, i.e., the off-cycle period of the second pulse cycle. In contrast to the method of operation illustrated in Fig. 2, the nominal pulse frequency is decreased and thus the nominal pulse period is set to be longer for the third pulse cycle and subsequent pulse cycles until the nominal pulse frequency is changed again according to this second mechanism. Specifically, the nominal pulse period may be set as the sum of the on-cycle period and of the determined off-cycle period of the second pulse, as shown in Fig. 3. Setting the nominal pulse frequency or nominal pulse period to a new value may either be done automatically by the pulsed DC power supply or after confirmation by an operator who may be notified, e.g., via a display.

[0027] In Fig. 3, the nominal pulse frequency is decreased, and thus the nominal pulse period T_{pulse} is increased. The nominal operating frequency may also be increased and the nominal pulse period may become shorter. For illustration, imagine that after the fourth pulse in Fig. 2, the nominal pulse period for the fifth pulse would be made shorter by setting the nominal pulse period as the sum of the on-cycle period and off-cycle period of the fourth pulse, instead of

adapting the on-cycle period as shown in Fig. 2. However, decreasing the nominal pulse frequency is believed to be less risky with respect to process stability of a sputter deposition process than increasing the nominal pulse frequency. But, for instance, if it is known that a specific sputter deposition process can stably work within a certain range of tolerable nominal pulse frequencies, then the nominal pulse frequency may be increased or decreased as long as it stays within the range of tolerable nominal pulse frequencies.

[0028] The second mechanism as described with respect to Fig. 3 ensures that the sputter targets are sufficiently discharged by determining a zero-line condition as a form of charge removal condition, and provides sufficient time for the actual current to reach fulfilment of the zero-line condition during an off-cycle.

[0029] The first mechanism illustrated in Fig. 2 and the second mechanism illustrated in Fig. 3 may also be used jointly in a pulsed DC power supply. The first mechanism may be used as a default mechanism, and the second mechanism is used if certain operation parameter mismatch conditions are met. For instance, if using the first mechanism leads to a situation where the on-cycle becomes unacceptably short, or in other words where the duty factor and thus the efficiency of the sputter deposition process becomes unacceptably low, this may be an indication that the nominal pulse frequency was set too high. Then, the pulsed DC power supply may switch to using the second mechanism, either automatically or semi-automatically with confirmation by an operator, before falling back to using the first mechanism again as default mechanism.

[0030] The pulsed DC power supply can, based on current measurements and evaluation if the measurement results fulfill specified conditions, automatically or semi-automatically ensure sufficient charge removal from sputter target(s), optimize the length of the on-cycle, i.e., optimize the duty factor, and set an appropriate nominal pulse frequency. The efficiency and stability of a sputter deposition process may thus be increased and arcing may be reduced considerably. Of course, the pulsed DC power supply may still additionally include dedicated arc suppression circuitry to counteract the formation of an arc once detected by the dedicated arc suppression circuitry. Triggering of one or more reverse pulses by the dedicated arc suppression circuitry to quench a detected arc could then take precedence over the regular unipolar pulse generation described herein.

[0031] According to embodiments described herein, a pulsed DC power supply is provided. The pulsed DC power supply is configured for providing unipolar pulsed DC power. The provision of unipolar pulsed DC power may be one operating mode of the pulsed DC power supply. The pulsed DC power supply may additionally be capable of other operating modes, for example a bipolar pulsed DC power mode. The pulsed DC power supply may be a voltage-controlled pulsed DC power supply. The pulsed DC power supply may be configured to drive a unipolar pulsed DC sputter deposition process. The pulsed DC power supply may be connectable to a sputter deposition system, specifically to one or more sputter targets.

[0032] The pulsed DC power supply includes a pulsing unit. The pulsed DC power supply may include a DC voltage source as a separate component. Alternatively, the pulsing unit may include a DC voltage source. Pulsing unit and DC voltage source may be integral with each other. The pulsing unit may be configured to shape DC voltage output by the DC voltage source, so as to form unipolar pulsed DC voltage. The actual unipolar pulsed DC voltage at the output of the pulsed DC power supply may depend on electrical properties of a system to which the pulsed DC power supply is connected. For the pulsed DC power supply, the system the pulsed DC power supply is connected may appear as a time-dependent, complex-valued impedance. Such a system may be sputter deposition system, but could be a test device mimicking the properties of a deposition system.

[0033] The pulsing unit is configured to set a nominal on-cycle DC voltage and to set a nominal off-cycle DC voltage. Nominal quantities are operating parameters set for the pulsed DC power supply, either by the pulsed DC power supply itself or by an operator. The pulsing unit may set the nominal on-cycle voltage and the nominal off-cycle voltage alternately. The nominal on-cycle DC voltage is set during on-cycles. An on-cycle lasts from the moment the nominal on-cycle DC voltage is set to the moment the subsequent nominal off-cycle DC voltage is set. The length in time of the on-cycle is called on-cycle period. The nominal off-cycle DC voltage is set during off-cycles. An off-cycle lasts from the moment the nominal off-cycle DC voltage is set to the moment the subsequent nominal on-cycle DC voltage is set. The length in time of the off-cycle is called the off-cycle period. The off-cycle may also be called a reverse pulse, and the off-cycle period may also be called a reverse pulse length or off time. The nominal, unipolar pulsed DC voltage thus has a square wave pattern, while the actual unipolar pulsed DC voltage may be disturbed by back-action of a system to which the pulsed DC power supply is coupled.

[0034] One on-cycle and one directly following off-cycle form a unipolar pulse cycle, also simply called a pulse cycle. The length in time of a pulse cycle is called a pulse period. The inverse of the pulse period is called pulse frequency. A nominal pulse frequency is also called an operating frequency of the pulsed DC power supply. The pulsing unit can be configured for alternatingly setting a nominal on-cycle DC voltage during on-cycles and a nominal off-cycle voltage during off-cycles of unipolar pulse cycles of the pulsed DC power supply.

[0035] The nominal on-cycle DC voltage may be set to a value in the range from -100 V to -1000 V, such as from -100 V to -200 V. The nominal off-cycle DC voltage may be set to a value in the range from zero Volts up to the nominal on-cycle DC voltage with inverse sign, e.g. up to a positive voltage from 100 V to 1000V. The nominal off-cycle DC voltage may in a range from 0 V to 100 V, such as from 0 to 20 V or from 5 to 20 V. The absolute value of the nominal off-cycle DC voltage may be at least five times smaller than the absolute value of the nominal on-cycle DC voltage, or even at least ten times smaller or even at least 20 times smaller. The nominal pulse frequency (operating frequency) may have a value in the range from 100 Hz to 200 KHz, specifically in the range from 100 kHz to 100 KHz, such as from 1 kHz to 100 kHz. The nominal pulse period, being the inverse thereof, may thus have a value in the range from 10000 μ s to 5 μ s, more specifically from 10000 μ s to 10 μ s, such as from 1000 μ s to 10 μ s.

[0036] The pulsed DC power supply includes a current measurement unit. The current measurement unit may be configured to measure the actual current at least during off-cycles, and possibly in addition also during on-cycles. The actual current during an off-cycle is called an off-cycle current. The current measurement unit is configured to measure the off-cycle current during an off-cycle. The current measurement unit may be an analog device with analog output. Alternatively, the current measurement unit may include an analog digital converter for converting analog measurement values to corresponding digital values. The current measurement unit is then regarded as a digital device due to outputting digital values.

[0037] The current measurement unit may be a current probe, specifically a DC current probe, or may include such a current probe. The current probe may include one or more Hall sensors. The current probe may generate analog measurement values. The current probe may generate a probe voltage proportional to the measured current, specifically the measured off-cycle current. The current measurement unit may include an analog digital converter configured to sample

and digitize the probe voltage or other analog measurement values representing the off-cycle current.

[0038] The pulsed DC power supply includes a zero-line determination unit. The current measurement unit may be configured to pass the measurement values, such as analog or digital values, to the zero-line determination unit. If analog values are passed to the zero-line determination unit, i.e., if the current measurement unit is an analog device, the zero-line determination unit may include an analog digital converter for converting the received analog measurement values to corresponding digital values. The zero-line determination unit is configured to determine the presence of a zero-line condition of the measured off-cycle current. The zero-line condition is present if the off-cycle current is zero or at least substantially zero, or is within a predetermined range. The predetermined range may include a current value of zero, but may alternatively exclude zero, e.g., if some bias is applied.

[0039] The off-cycle current can be said to be substantially zero if a current value is in a zero-line condition range, such as between -0.1 A and 0.1 A . Since the off-cycle current may be represented by measurement values such as the probe voltage of a current probe, the probe voltage being proportional to the measured off-cycle current, the zero-line condition may be determined to be present if these values are zero or substantially zero. In this context, substantially zero means that the measurement values representing the off-cycle current values are within a specific range such that the off-cycle current values, which the measurement values represent, are within the zero-line condition range. For instance, if the probe voltage of a current probe is k times the measured off-cycle current, k being a proportionality constant, then the zero-line condition is determined to be present if the probe voltage is in the range from $-k*0.1\text{ V}$ to $k*0.1\text{ V}$.

[0040] The zero-line determination unit may be configured to analyze the measurement values of the measured off-cycle current, e.g., sampled, digitized measurement values of a current probe. The zero-line determination unit may be configured to determine when the probe voltage from a current probe is zero or at least substantially zero. If the probe voltage or other measurement values representing the off-cycle current is/are found to be zero or at least substantially zero, the zero-line determination unit determines that a zero-line condition of the measured off-cycle current is present. The zero-line determination unit may generate a signal indicating the presence of a zero-line condition, e.g., a digital signal, which may be as small as 1 bit (e.g., a logical one). The signal may be fed to the pulsing unit.

[0041] The pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the zero-line condition of the measured off-cycle current. That means, a next pulse cycle starting with an on-cycle may be triggered upon detection of the presence of the zero-line condition. The pulsing unit may set the nominal on-cycle DC voltage when receiving, from the zero-line determination unit, the signal indicating the presence of a zero-line condition of the measured off-cycle current. The zero-line determination unit may be a sub-component of the pulsing unit or a separate component.

[0042] Fig. 4 shows a pulsed DC power supply 100 to illustrate embodiments described herein. The pulsed DC power supply 100 is configured to provide unipolar pulsed DC power, e.g., for a sputter deposition process. The pulsed DC power supply 100 includes a pulsing unit 110, a current measurement unit 120, and a zero-line determination unit 130. For illustration of the respective functions, the pulsing unit 110 is shown with a schematic graph of the nominal pulsed DC voltage, the current measurement unit 120 is shown with a schematic graph of the actual current, and the zero-line determination unit 130 is shown with a schematic graph of the trigger points indicating the presence of a zero-line condition of the actual current. The pulsed DC power supply 100 and the pulsing unit 110, current measurement unit 120 and zero-line determination unit 130 may be configured as in the embodiments described herein.

[0043] The pulsed DC power supply may be configured to determine an off-cycle period of the off-cycle from the time difference between the setting of the nominal off-cycle voltage of the off-cycle and the determining of the presence of the zero-line condition. The pulsed DC power supply may be configured to determine an on-cycle period of an on-cycle from or as the time difference between a nominal pulse period and the determined off-cycle period. The nominal pulse period is the inverse of a nominal pulse frequency of the pulsed DC power supply. The determinations may be made by the pulsing unit. The pulsing unit may be configured to maintain the nominal on-cycle DC voltage during the determined on-cycle period, at least during a subsequent pulse cycle following the pulse cycle based on which the determination of the on-cycle period was made. The first mechanism described with respect to Fig. 2 is an example of how the determination and adaptation of the on-cycle period may be made from pulse cycle to pulse cycle.

[0044] The pulsed DC power supply may be configured to determine an actual pulse period of a first pulse cycle from the time difference between setting the nominal on-cycle DC voltage for the first pulse cycle and setting the nominal on-cycle DC voltage for a subsequent second

pulse cycle upon determination of the presence of the zero-line condition. The determination may be made by the pulsing unit. The pulsing unit may be configured to set a nominal operating frequency of the pulsed DC power supply to correspond to the inverse of the determined actual pulse period of the first pulse cycle.

[0045] The pulsing unit may be configured to set the nominal operating frequency in this way if the inverse of the determined actual pulse period of the first pulse is in a range of tolerable nominal operating frequencies. The range of tolerable nominal operating frequencies may depend on the specific sputter deposition process for which the pulsed DC power supply provides unipolar pulsed DC power. The range of tolerable nominal operating frequencies may, e.g., consist of frequencies within ± 20 kHz or ± 10 kHz of an initial nominal operating frequency chosen and set by an operator. Since lowering the operating frequency is believed to be safer with respect to the stability of the sputter deposition process than increasing the operating frequency, the range of tolerable nominal operating frequencies may be chosen asymmetric around an initial nominal operating frequency chosen and set by an operator. For instance, the range of tolerable nominal operating frequencies may be from $F_0 - 20$ kHz to $F_0 + 5$ kHz, where F_0 is the initial nominal operating frequency.

[0046] Alternatively, the pulsing unit may be configured to set the nominal operating frequency to the inverse of the determined actual pulse period of the first pulse only if the inverse of determined actual pulse period of the first pulse is lower than the current nominal operating frequency. That means, the pulsing unit could only lower the nominal operating frequency automatically. For increasing the operating frequency, confirmation of an operator would be needed. The second mechanism described with respect to Fig. 3 is an example of how the nominal operating frequency (nominal pulse frequency) can be set to a different value.

[0047] The pulsed DC power supply may be configured to adapt either the on-cycle period of a pulse cycle based on the length of the off-cycle of the preceding pulse cycle or to adjust the nominal pulse frequency (nominal operating frequency), wherein the decision if the on-cycle period shall be adapted or the nominal pulse frequency depends on one or more specific conditions, herein called operating parameter mismatch conditions.

[0048] The pulsed DC power supply may be configured to determine an off-cycle period of the off-cycle from the time difference between setting the nominal off-cycle voltage of the off-cycle and determining the presence of the zero-line condition. The pulsed DC power supply is

configured to perform the following evaluations and corresponding actions. If an operating parameter mismatch condition that depends on the determined off-cycle period is not present then the pulsed DC power supply determines an on-cycle period of an on-cycle from the difference between a pulse period and the off-cycle period. The pulse period is the inverse of a nominal operating frequency of the pulsed DC power supply. The pulsing unit of the pulsed DC power supply then maintains the nominal on-cycle DC voltage for the duration of the determined on-cycle period. If the operating parameter mismatch condition is present then the pulsed DC power supply changes the nominal operating frequency automatically or notifies an operator who may confirm or decline the change of the nominal operating frequency. The nominal operating frequency may be changed in the ways described herein.

[0049] Adjustment of the on-cycle period may be the default action, and adjustment of the nominal operating frequency may only be made if an operating parameter mismatch condition is present, i.e., fulfilled. One operation parameter mismatch condition may be dropping of the duty factor below a threshold duty factor. The threshold duty factor may be chosen from the range 0.8 to 0.95, such as 0.8 or 0.85. The pulsed DC power supply may evaluate if adjustment of the on-cycle period for the subsequent pulse cycle would lead to a duty factor below the threshold duty factor. If this is the case, i.e., if the operating parameter mismatch condition is determined, then the nominal pulse frequency is changed, and else the on-cycle period is adjusted. Other operating parameter mismatch conditions may be specified alternatively or in addition, so as to coordinate when to use adjustment of the on-cycle period and when to use adjustment of the nominal operating frequency.

[0050] The pulsed DC power supply may include an operator interface. The operator interface may include at least one input device, e.g., keyboard, mouse, touch screen and the like, and at least one output device, e.g., a display or the touch screen. The output device may be configured to output notifications or alerts to an operator, possibly requesting operator input via the input device. The output device may be configured to output a status of the pulsed DC power supply, including, e.g., the currently set nominal operating parameters like nominal operating frequency, nominal on-cycle voltage, nominal off-cycle voltage etc., and possibly including momentary or time-averaged values of variables such as the off-cycle period, on-cycle period etc. Time-averaging may be beneficial because momentary changes of the variables may be too fast for an operator to see. The pulsed DC power supply may include a memory for storing, e.g., the currently set nominal operating parameters, and conditions that are to be applied such

as operating mismatch conditions, charge-removal conditions etc. The pulsed DC power supply may be configured so that an operator can change these conditions and/or can change nominal operating parameters, e.g., via the input device. The memory may also store log files of a monitored sputter deposition process, e.g., for analysis purposes.

[0051] According to further embodiments, a sputter deposition system is provided. The sputter deposition system includes a sputter target and a pulsed DC power supply according to embodiments described herein. The pulsed DC power supply is connected to the sputter target to provide unipolar pulsed DC power to the sputter target.

[0052] Fig. 5 shows a sputter deposition system 500 for illustration. The sputter deposition system 500 includes a sputter target 510 connected to a pulsed DC power supply 210, and a sputter target 520 connected to a pulsed DC power supply 220. The sputter targets 510, 520 may be rotatable sputter targets, as indicated by the axis A and the arrow drawn in the sputter target 510. Sputter material from the sputter target 510 and from the sputter target 520 may be deposited on a substrate 10.

[0053] The sputter deposition system may include N sputter targets and N corresponding pulsed DC power supplies, where N may be in the range from 1 to 30, such as from 1 to 24 or from 2 to 24. The N pulsed DC power supplies may be integrated into one pulsed DC power system serving all N sputter targets. The sputter target(s) may act as cathode(s) during a sputter deposition process. The sputter deposition system may include one or more anodes, e.g., anode bars, which may be arranged between the sputter targets. Alternatively, a sputter chamber may form the anode, e.g., an electrically grounded sputter chamber. Each pulsed DC power supply may be connected to a sputter target and an anode to close the electrical circuit.

[0054] According to further embodiments, a method of operation of a pulsed DC power supply is provided. The method features may be executed automatically by the pulsed DC power supply, and may specifically be executed by the units described herein, such as measurement units like current probes, evaluation units like the zero-line condition determination unit, and pulsing units. Some method features may be executed semi-automatically after input from an operator. The pulsed DC power supply provides unipolar pulsed DC power, at least within one operating mode of the pulsed DC power supply. The pulsed DC power supply may be connected to a sputter target of a sputter deposition system.

[0055] Fig. 6 illustrates a method 600 of operation of a pulsed DC power supply. The method includes setting a nominal on-cycle DC voltage for a first pulse cycle, shown at reference sign 610. The method may include outputting an actual on-cycle DC voltage and an actual on-cycle DC current by the pulsed DC power supply. The method includes setting a nominal off-cycle DC voltage, shown at reference sign 620, to trigger an off-cycle of the first pulse cycle, and measuring an off-cycle current, shown at reference sign 630. The off-cycle current is the actual off-cycle current of the off-cycle of the first pulse cycle. The method includes, as shown at reference sign 640, determining a presence of a zero-line condition of the off-cycle current from the measurement, i.e., from the measurement of the off-cycle current. The method includes, as shown at reference sign 650, setting a nominal on-cycle DC voltage for a second pulse cycle when the zero-line condition is determined to be present.

[0056] Setting the nominal on-cycle DC voltage for the first pulse cycle may be made by a pulsing unit of the pulsed DC power supply. Outputting on-cycle DC voltage and on-cycle DC current may be effected by the pulsing unit, possibly in connection with output from an external DC voltage source if the pulsing unit does not include an internal DC voltage source. Setting the nominal off-cycle DC voltage may be made by the pulsing unit. Measuring the off-cycle current of the off-cycle of the first pulse cycle may be made by a measurement unit. Determining the presence of the zero-line condition may be made by a zero-line determination unit. Setting the nominal on-cycle DC voltage for the second pulse cycle may be made by the pulsing unit.

[0057] The method may include determining an off-cycle period from the time difference between setting the nominal off-cycle DC voltage and the moment of determining the presence of the zero-line condition. The method may include determining an on-cycle period from the difference between a nominal pulse period and the determined off-cycle period. The nominal pulse period is the inverse of a nominal operating frequency of the pulsed DC power supply. The determinations may be made by the zero-line determination unit or by the pulsing unit. The method may include maintaining the nominal on-cycle DC voltage of the second pulse cycle for the duration of the determined on-cycle period. The method may include setting the nominal off-cycle DC voltage to trigger an off-cycle of the second pulse cycle upon expiry of the determined on-cycle period.

[0058] The method may include determining an actual pulse period of the first pulse cycle from the time difference between setting the nominal on-cycle DC voltage for the first pulse cycle

and setting the nominal on-cycle DC voltage for the second pulse cycle. The method may include setting a nominal operating frequency to correspond to the inverse of the determined actual pulse period of the first pulse cycle.

[0059] The method may include determining an off-cycle period from the time difference between setting the nominal off-cycle DC voltage the off-cycle and determining the presence of the zero-line condition. The method may further include the following: if an operating parameter mismatch condition that depends on the determined off-cycle period is not present then determining an on-cycle period from the difference between a nominal pulse period and the determined off-cycle period, and maintaining the nominal on-cycle DC voltage of the second pulse cycle for the duration of the determined on-cycle period, and if the operating parameter mismatch condition is present then changing the nominal operating frequency.

[0060] The operating parameter mismatch condition may not be present, i.e., absent or not fulfilled, if a tentative duty factor is larger than or equal to a threshold duty factor. The tentative duty factor is the difference between the nominal pulse period and the determined off-cycle period divided by the nominal pulse period. The operating parameter mismatch condition is present if the tentative duty factor is smaller than the threshold duty factor. If the nominal operating frequency is changed, then the nominal operating frequency may be maintained for subsequent pulse cycles until the nominal operating frequency is changed again.

[0061] The method may include the features: setting the on-cycle DC voltage for the on-cycle of the present pulse cycle upon determination of the presence of the zero-line condition, setting, the off-cycle DC voltage for the present pulse cycle, measuring the off-cycle current of the off-cycle of the present pulse cycle, and determining the presence of the zero-line condition of the off-cycle current of the present pulse cycle. Once the presence of the zero-line condition is determined, the next pulse cycle becomes the present pulse cycle, and the features may be repeated.

[0062] As a further example, a pulsed DC power supply is provided. The pulsed DC power supply is configured to output unipolar pulsed DC power. The pulsed DC power supply is configured to stop an off-cycle of a pulse cycle based on measurements of at least one electrical quantity of the pulsed DC power supply. Stopping may include starting an on-cycle period of a subsequent pulse cycle. The pulsed DC power supply may be configured to tune an off-cycle period of a pulse cycle based on measurements of at least one electrical quantity of the pulsed

DC power supply. The pulsed DC power supply may be configured to tune the off-cycle period of every pulse cycle. The off-cycle period may be adjusted from pulse cycle to pulse cycle. The length of the off-cycle may be variable, depending on the measurements of the at least one electrical quantity.

[0063] The pulsed DC power supply may include a measurement unit for measuring the at least one electrical quantity of the pulsed DC power supply. The at least one electrical quantity may be measured at the output of the pulsed DC power supply. The at least one electrical quantity may be at least one quantity selected from the group consisting of voltage, current, and time derivatives thereof. The pulsed DC power supply may include an evaluation unit configured to evaluate the measurement values of the measurement unit and to determine the presence of a charge removal condition. The pulsed DC power supply may include a pulsing unit for setting a nominal on-cycle DC voltage during an on-cycle of a pulse cycle and for setting a nominal off-cycle voltage during an off-cycle of a pulse cycle. The pulsing unit may be configured to set the nominal on-cycle DC voltage upon determination of the presence of the charge-removal condition.

[0064] The at least one electrical quantity may current, in particular at least off-cycle current. The measurement unit may include a current probe for measuring the current at least during an off-cycle as described herein. The charge-removal condition may be the zero-line condition described herein.

[0065] The charge-removal condition may alternatively be different from the zero-line condition. For instance, the charge-removal condition may be a zero-energy condition of the reverse pulse. That means, the pulsed DC power supply may be configured to determine when zero energy or substantially zero energy is left in the system to which the pulsed DC power supply provides unipolar pulsed DC power. The zero-energy condition of the reverse pulse may be determined from integrating the product of voltage and current over time. The zero-energy condition may be determined to be present when this integral is zero or substantially zero. The measurement unit may include a voltage measurement device and a current measurement device. The evaluation unit may be configured to evaluate voltage measurement values from the voltage measurement device and current measurement values from the current measurement device, and to determine the presence of a zero-energy condition.

[0066] The pulsed DC power supply may further be configured to adjust an on-cycle period of a pulse cycle based on the off-cycle period of the preceding pulse cycle. The pulsed DC power supply may be configured to adjust a nominal pulse frequency of the pulsed DC power supply based on an off-cycle period of a pulse cycle. The pulsed DC power supply may include or exhibit all other features described herein with respect to embodiments, including mechanisms to adjust on-cycle periods, nominal pulse frequency, or both on-cycle periods and nominal pulse frequency based on specific conditions as described herein.

[0067] According to a further example, a method of operation of such a pulsed DC power supply is provided. The method includes stopping an off-cycle of a unipolar pulse cycle based on measurements of at least one electrical quantity of the pulsed DC power supply. Stopping the off-cycle may include stopping the off-cycle upon determination that a charge-removal condition is fulfilled. Fulfillment of the charge-removal condition depends on the measurements of the at least one electrical quantity. The charge-removal condition may be as described hereinabove.

[0068] The method may include execution of some or all functions of the pulsed DC power supply as described herein. Further, a method of operation of the sputter deposition system is provided, which may include execution of some or all functions of the sputter deposition system described herein. A further aspect is directed to the use of a pulsed DC power supply to provide unipolar pulsed DC power, such as to a sputter target of a sputter deposition system as described herein. The use may include automatic determination of the length of the off-cycles (i.e., off-cycle periods) of the unipolar pulse cycles of the nominal voltage, as described hereinabove. A further aspect is directed to a method of sputtering a substrate using a sputter deposition system as described herein.

[0069] The terms and expressions which have been employed herein are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described or portions thereof. While the foregoing is directed to embodiments, other and further embodiments may be devised without departing from the scope, and the scope is determined by the claims that follow.

CLAIMS

1. A pulsed DC power supply (100) for providing unipolar pulsed DC power, comprising:
a pulsing unit (110) for alternately setting a nominal on-cycle DC voltage during on-cycles and a nominal off-cycle voltage during off-cycles of unipolar pulse cycles of the pulsed DC power supply;
a current measurement unit (120) configured to measure an off-cycle current during an off-cycle; and
a zero-line determination unit (130) configured to determine a presence of a zero-line condition of the measured off-cycle current;
wherein the pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the zero-line condition of the measured off-cycle current.
2. The pulsed DC power supply according to claim 1, wherein the pulsed DC power supply is configured to determine an off-cycle period of the off-cycle from a time difference between setting the nominal off-cycle voltage of the off-cycle and determining the presence of the zero-line condition, and the pulsed DC power supply is configured to determine an on-cycle period of an on-cycle from a time difference between a nominal pulse period and the determined off-cycle period, the nominal pulse period being the inverse of a nominal pulse frequency of the pulsed DC power supply; and
wherein the pulsing unit is configured to maintain the nominal on-cycle DC voltage during the determined on-cycle period.
3. The pulsed DC power supply according to claim 1, wherein the pulsed DC power supply is configured to determine an actual pulse period of a first pulse cycle from a time difference between setting the nominal on-cycle DC voltage for the first pulse cycle and setting the nominal on-cycle DC voltage for a subsequent second pulse cycle upon determination of the presence of the zero-line condition, and
wherein the pulsed DC power supply is configured to set a nominal operating frequency of the pulsed DC power supply to correspond to the inverse of the determined actual pulse period of the first pulse cycle.
4. The pulsed DC power supply according to claim 1, wherein the pulsing unit is configured to determine an off-cycle period of the off-cycle from a time difference between setting the nominal off-cycle voltage of the off-cycle and determining the presence of the zero-line condition; and

if an operating parameter mismatch condition that depends on the determined off-cycle period is not present then to determine an on-cycle period of an on-cycle from a time difference between a nominal pulse period and the off-cycle period, the nominal pulse period being the inverse of a nominal operating frequency of the pulsed DC power supply, and maintaining the nominal on-cycle DC voltage during the determined on-cycle period; and

if the operating parameter mismatch condition is present then to change the nominal operating frequency.

5. The pulsed DC power supply according to any of claims 1-4, wherein the current measurement unit includes at least one of: a current probe for measuring the off-cycle current and outputting corresponding measurement values representing the off-cycle current, and an analog digital converter for converting measurement values representing the off-cycle current to digital values.

6. The pulsed DC power supply according to any of the claims 1-5, wherein the zero-line condition is determined to be present by the zero-line determination unit when measurement values representing the measured off-cycle current are zero or are within a predetermined range.

7. A pulsed DC power supply for providing unipolar pulsed DC power, comprising:
a pulsing unit configured to set a nominal on-cycle DC voltage during an on-cycle of a unipolar pulse cycle of the pulsed DC power supply and configured to set a nominal off-cycle voltage during an off-cycle of a unipolar pulse cycle of the pulsed DC power supply;
a measurement unit configured to measure at least one electrical quantity of the pulsed DC power supply; and
an evaluation unit configured to determine the presence of a predetermined condition from an evaluation of measurement values of the measured at least one electrical quantity,
wherein the pulsing unit is configured to set the nominal on-cycle DC voltage upon determination of the presence of the predetermined condition.

8. The pulsed DC power supply according to claim 7, wherein

(a) the at least one electrical quantity that is measured includes voltage and current and the predetermined condition is a zero-energy condition, or

(b) wherein the at least one electrical quantity that is measured includes off-cycle current and the predetermined condition is a zero-line condition of the measured off-cycle current.

9. A sputter deposition system (500), comprising:

a sputter target (510, 520); and

a pulsed DC power supply (100; 210, 220) according to any of claims 1 to 8,

wherein the pulsed DC power supply is connected to the sputter target to provide unipolar pulsed DC power to the sputter target.

10. A method (600) of operation of a pulsed DC power supply that provides unipolar pulsed DC power, the method comprising:

setting (610) a nominal on-cycle DC voltage for a first pulse cycle of the pulsed DC power supply, and outputting an on-cycle DC voltage and an on-cycle DC current by the pulsed DC power supply;

setting (620) a nominal off-cycle DC voltage to trigger an off-cycle of the first pulse cycle;

measuring (630) an off-cycle current by the pulsed DC power supply;

determining (640) a presence of a zero-line condition of the off-cycle current from the measurement; and

setting (650) a nominal on-cycle DC voltage for a second pulse cycle when the zero-line condition is determined to be present.

11. The method according to claim 10, comprising:

determining an off-cycle period from a time difference between setting the nominal off-cycle DC voltage and determining the presence of the zero-line condition;

determining an on-cycle period from the difference between a nominal pulse period and the off-cycle period, the nominal pulse period being the inverse of a nominal operating frequency of the pulsed DC power supply; and

maintaining the nominal on-cycle DC voltage of the second pulse cycle during the determined on-cycle period.

12. The method according to claim 10, comprising:

determining an actual pulse period of the first pulse cycle from a time difference between setting the nominal on-cycle DC voltage for the first pulse cycle and setting the nominal on-cycle DC voltage for the second pulse cycle; and

setting a nominal operating frequency to correspond to the inverse of the determined actual pulse period.

13. The method according to claim 10, comprising:

determining an off-cycle period from a time difference between setting the nominal off-cycle DC voltage of the off-cycle and determining the presence of the zero-line condition;

if an operating parameter mismatch condition that depends on the determined off-cycle period is not present then determining an on-cycle period from the difference between a nominal pulse period and the determined off-cycle period, the nominal pulse period being the inverse of a nominal operating frequency of the pulsed DC power supply, and maintaining the nominal on-cycle DC voltage of the second pulse cycle for a length of time corresponding to the determined on-cycle period; and

if the operating parameter mismatch condition is present then changing the nominal operating frequency.

14. The method according to claim 13, wherein the operating parameter mismatch condition is not present if a tentative duty factor is larger than or equal to a threshold duty factor, wherein the tentative duty factor is a time difference between the nominal pulse period and the determined off-cycle period divided by the nominal pulse period, and wherein the operating parameter mismatch condition is present if the tentative duty factor is smaller than the threshold duty factor.

15. The method according to any of the claims 10-14, wherein measuring the off-cycle current by the pulsed DC power supply includes generating measurement values representing the off-cycle current, and wherein determining the presence of the zero-line condition of the off-cycle current includes evaluating if the measurement values are zero or are within a predetermined range.

Fig. 1

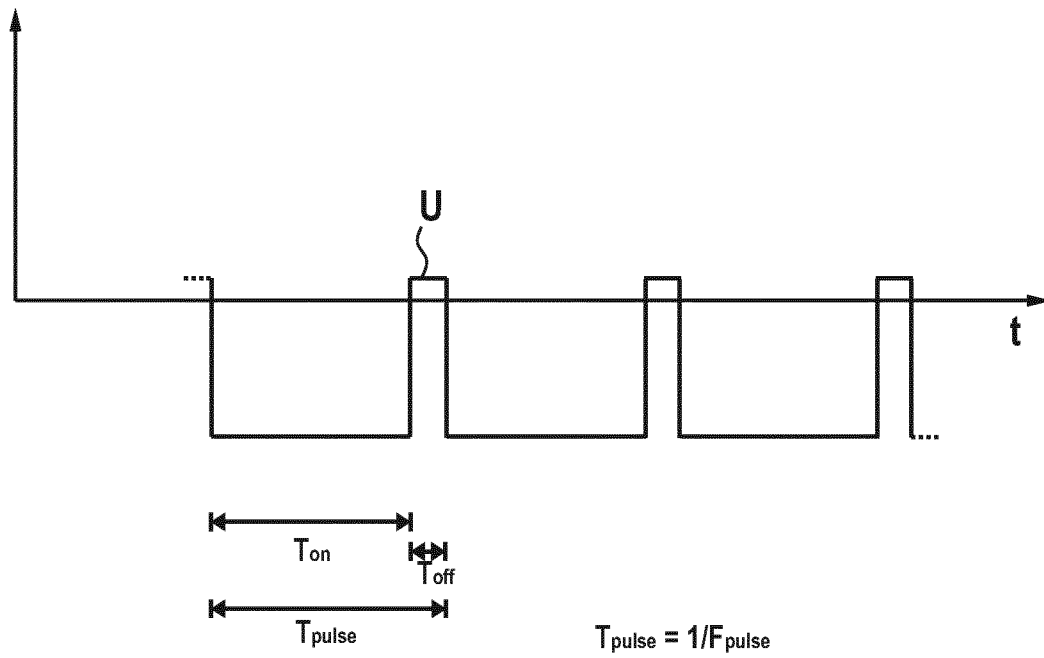


Fig. 2

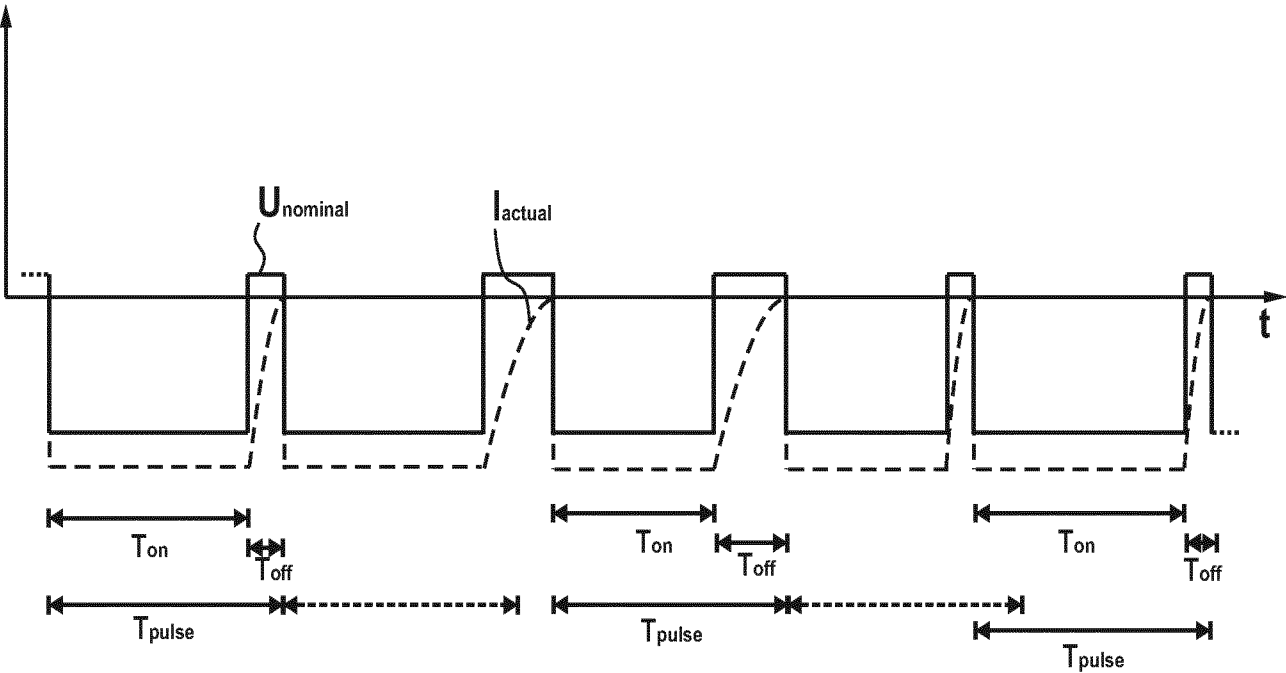


Fig. 3

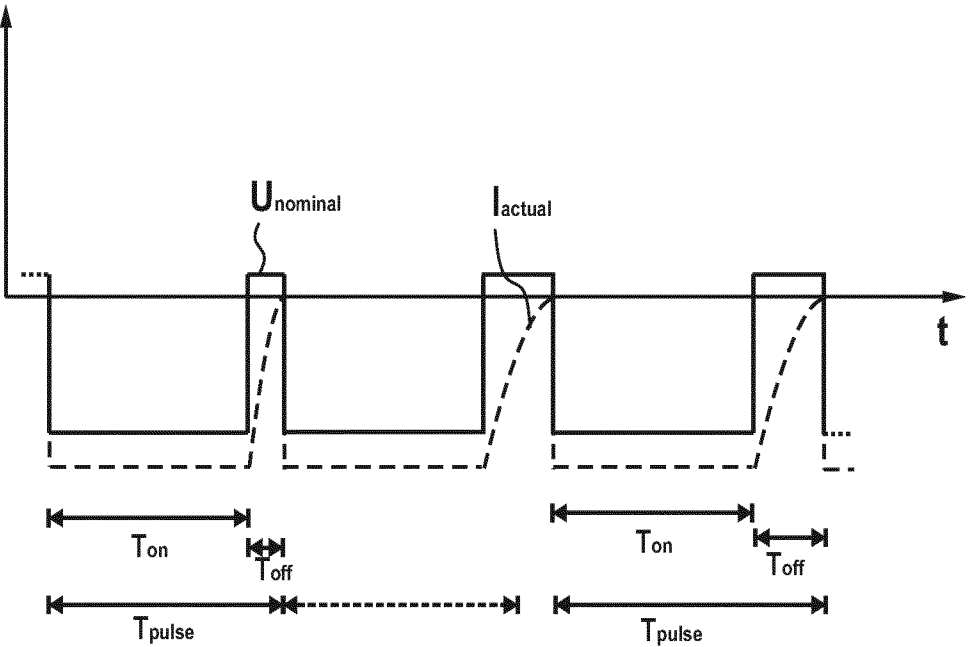


Fig. 4

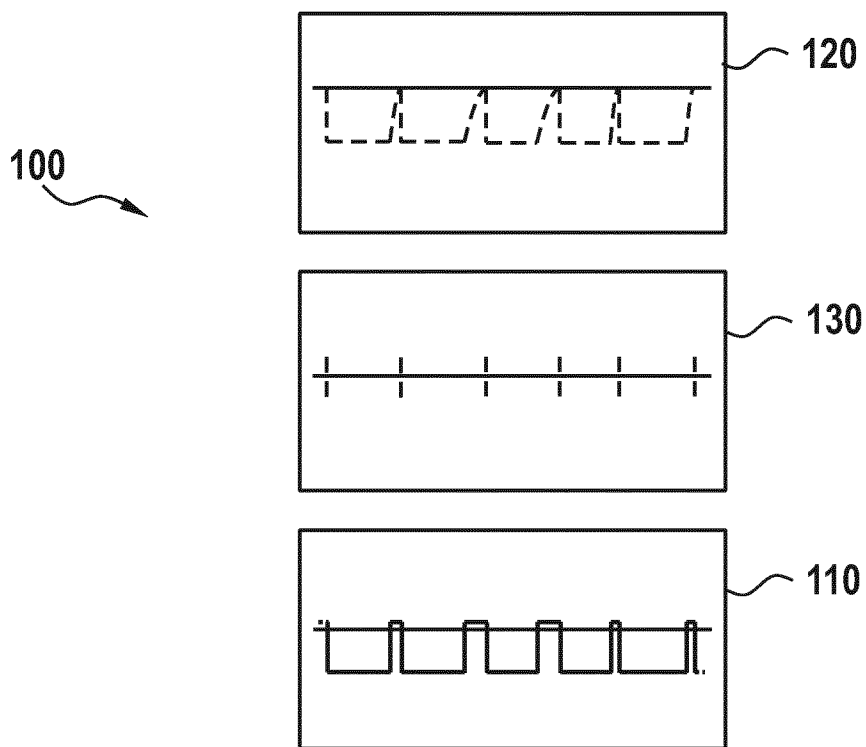


Fig. 5

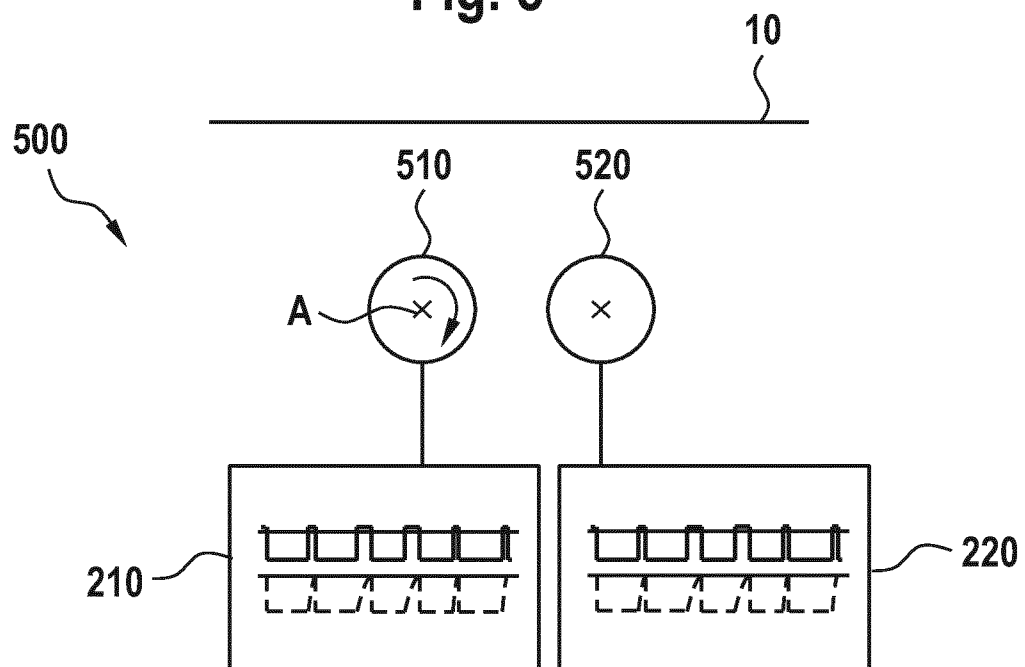
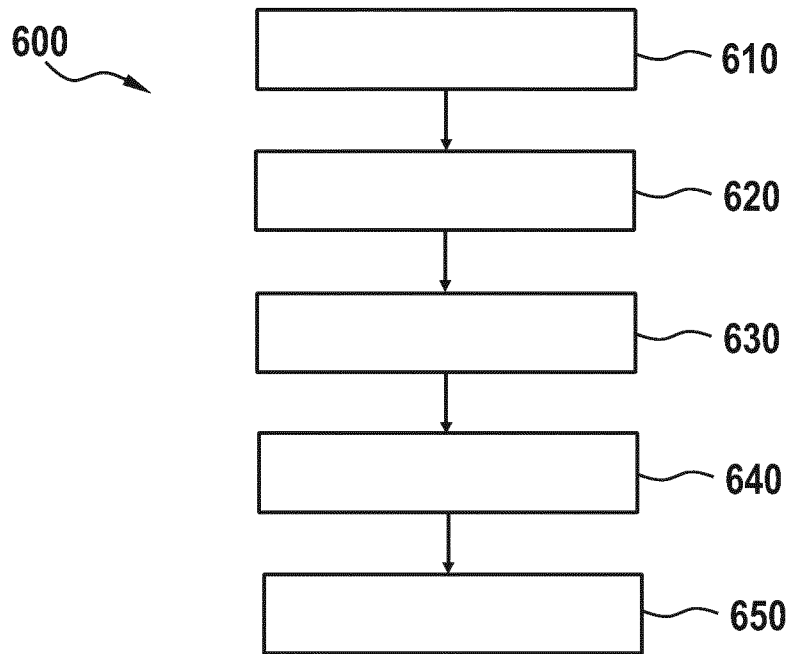


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/061190

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01J37/34 H01J37/32
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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X	EP 0 639 655 A1 (ASAHI GLASS CO LTD [JP]) 22 February 1995 (1995-02-22)	7
A	figures 1-4 page 6, line 5 - line 49 page 7, line 32 - line 43	1-6,8-15
A	----- WO 2011/143331 A1 (ADVANCED ENERGY IND INC [US]; NAUMAN KENNETH E [US]; FINLEY KENNETH [U] 17 November 2011 (2011-11-17) figures 1,4,5,8A, 8B, 9, 10 paragraph [0010] paragraph [0012] paragraph [0016] paragraph [0045] - paragraph [0055] paragraph [0067] - paragraph [0069] paragraph [0078] - paragraph [0086] ----- -/-	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

16 January 2018

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24/01/2018

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Hochstrasser, M

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/061190

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 2 157 205 A1 (SULZER METAPLAS GMBH [DE]) 24 February 2010 (2010-02-24) figures 2a-2d, 5-8 paragraph [0037] paragraph [0082] - paragraph [0099] -----	1-15

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International application No

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